Examining Near-source Effects in the Far Field

F. N. App, R. J. Bos, T. N. Dey, E. M. Jones, J. R. Kamm, S. R. Taylor

EES Division, Los Alamos National Laboratory, Los Alamos NM 87545

Abstract

A fundamental objective of the S-6 (physical basis for discrimination) sub-task of the CTBT R&D Seismic Monitoring Program at Los Alamos is to analyze the sensitivity of the regional signal to source configuration, material properties, geologic layering and structure, along with complications along the path of the signal. Our approach is to combine the results of conventional analysis of field data from explosions and earthquakes with results of numerical models of actual and idealized situations. Existing first-principles, finite difference codes allow us to examine source effects in the non-linear regime; linking the results of these near-source calculations to finite difference, anelastic wave propagation codes allows us to examine the effect of various source region and propagation path characteristics on signals observed at regional distances. An investigation of discriminant differences for the DIVIDER and CORREO underground nuclear explosions is provided as an example of the approach used.

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<u>Objective</u>

A fundamental objective of the S-6 (physical basis for discrimination) sub-task of the CTBT R&D Seismic Monitoring Program at Los Alamos is to analyze the sensitivity of the regional signal to source configuration, material properties, geologic layering and structure, along with complications along the path of the signal. Our approach is to combine the results of conventional analysis of field data from explosions and earthquakes with results of numerical models of actual and idealized situations. Existing first-principles, finite difference codes allow us to examine source effects in the non-linear regime; linking the results of these near-source calculations to finite difference, anelastic wave propagation codes allows us to examine the effect of various source region and propagation path characteristics on signals observed at regional distances. This report describes the progress thus far in the application of these capabilities.

<u>Preliminary results</u>

Our investigation of discriminant differences for the DIVIDER and CORREO underground nuclear tests provides one example of our approach. Our first efforts at generating regional synthetic seismograms from realistic source simulations involved linking the "strong motion" code TOODY (Swegle, 1978) to a LANL reflectivity code. This coupling approach was validated on a simple problem involving a purely elastic material (Taylor and App, 1994). We proceeded to calculate regional synthetics for actual underground nuclear tests conducted in Area 3 of the Nevada Test Site (NTS). The near-source geology for the selected events is relatively simple, except for one very well characterized fault scarp. Both close-in and regional seismic measurements are used in ground truthing the calculations.

Figure 1 shows a comparison between the regional signals recorded at the LLNL Kanab regional seismic station for the DIVIDER and CORREO underground nuclear tests, as well as synthetics generated from calculations of two highly idealized versions of these tests[1]. The events were conducted in similar rocks, with similar yields and explosion point depths. The paths from the two events to the Kanab station (approximately 250 km) are nearly equal: the total distance from CORREO is about 2 km greater than that from DIVIDER.

In both the calculations and measurements for the two events there are differences in the seismograms, most notably in the Pg to Lg ratio. This ratio, which is a promising discriminant between earthquakes and explosions (Taylor et al., 1989), is greater for DIVIDER than for CORREO, implying that DIVIDER has a more explosion-like signature than CORREO. The only known difference between the two sites is that DIVIDER is located in close proximity to the aforementioned fault scarp, whereas CORREO has no such nearby geologic complication.

Figure 2 is a geologic cross section of the DIVIDER site; the CORREO site is similar, but without the scarp. Both tests were conducted above a very large impedance discontinuity caused by Tertiary aged, porous tuffs overlying Paleozoic (Pz) aged limestone. Figure 3a is a snapshot from the idealized CORREO calculation, showing the velocity field at 1 s, with the lengths of the lines (vectors) being proportional to the amplitude of the particle motion and the directions indicating the direction of motion. From the strong transverse motion in the Pz, it is apparent that a very strong conversion

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[1] By this we mean that we idealized certain specific test configurations to fit into a more manageable parameter study, but retained the important elements of the tests.

from primary compression (p) wave to shear (s) occurs at the tuff/Pz interface. Theory predicts that such conversions are maximized at angles of incidence between about 60 to 85 degrees[2]. Converted s-waves are believed to be strong contributors to Lg at regional distances, especially when the compressional velocity of the source material is low compared to the mantle shear wave velocity, as it is in this case (Xie and Lay, 1994). Figure 3b is the calculated velocity field for the idealized DIVIDER calculation, for which the picture is somewhat different. It appears that for DIVIDER more p-wave and less s-wave energy is transmitted into the Pz case than for CORREO, providing us with a working hypothesis for the observed differences at regional distances. For CORREO, the large expanse of Pz interface allows relatively more p-to-s conversion than for DIVIDER, for which the p-wave generated by the explosion has a higher angle of incidence at the Pz surface (due to the geometry); indeed, for DIVIDER there are no angles of incidence exceeding about 60 degrees, so that conversion to s-wave energy is less efficient, and transmission of p-waves more efficient. In the absence of strong effects elsewhere, it is plausible that DIVIDER should appear more explosion-like than CORREO.

It would be premature to conclude from this case that events conducted near large scarps generally would appear more explosion-like, and, therefore, that we need not worry about explosions being hidden near faults. The CORREO-DIVIDER case may be very special to the NTS. The calculations do suggest that events conducted in close proximity to a strong, near-horizontal discontinuity can generate sufficient shear close-in to influence regional waveforms, and thus cause such explosions to appear more earthquake-like. This effect may contribute to the observed reduced performance of the Pg/Lg discriminant for explosions at the NTS compared to other parts of the world.

The above example demonstrates one application of calculations to the discrimination task. These calculations, however, were two-dimensional; therefore, they are limited primarily to effects that can be described in two dimensions[3]. The remainder of this paper describes the other developments underway at LANL to address 3-D effects as well as to increase the flexibility to our current 2-D capabilities.

To investigate 3-D near-source effects, we have undertaken a series of calculations with the RAGE code. RAGE is an adaptive mesh refinement (AMR) "strong motion" code that provides state-of-the-art numerical treatments to reduce the number of computations in a 3-D model to a manageable number. RAGE was developed by SAIC and is being used at Los Alamos. Through SAIC, we are evaluating RAGE for use in modeling mining blasts, geologic structure, and other inherently 3-D configurations. Figure 4 shows the computational mesh from a test calculation involving a pressurized sphere in an elastic half-space. This problem is the same model mentioned above in connection with Taylor and App (1994). There are three main phases after reflection from the free surface: the main compressional-dilatational wave (p), the rarefaction from the surface (pP), and the converted shear wave (pS). As shown in this figure, the RAGE AMR algorithm refines the mesh where p and pP are strongest; the present algorithm requires further refinement to adequately capture the region about the pS shear wave.

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[2] From the Zoeppritz equations, which express the partition of energy when a plane wave impinges on an acoustic-impedance contrast.

[3] Note that the case involving a scarp is inherently three-dimensional; however, auxiliary calculations were made to evaluate the influence of a conical vs. planar fault on shear conversions, and it was determined that in this instance we could tolerate such a geometric simplification. A complete description of the calculations is beyond the scope of this paper.

To address 3-D effects at regional distances, we have acquired the AFD-3D code. This elastic wave code, originally written by Ningya Cheng (1994), is fourth order in space and second order in time, making it relatively efficient to use in propagating close-in signals to regional distances (i.e., one can retain the desired frequency response with fewer computational zones and cycles). We are currently establishing linkages of our 2-D and 3-D strong motion codes to AFD-3D for generating regional synthetics. We have implemented the anelasticity model of Emmerich & Korn (1987) and are in the process of validating that methodology. Additionally, we have modified AFD-3D to perform 2-D cylindrically symmetric computations; this approach, an alternative to the reflectivity method, has the advantage that more complicated geologies can be simulated. We intend to incorporate a surface topography model into AFD-3D, with which we shall address the issue of topography-induced surface wave modification.

Recommendations and Future Plans

The computational investigations discussed above provide an avenue to deeper understanding of the physical processes involved in shaping the regional seismic signal. The application of properly validated codes to various source configurations will allow us to extrapolate to situations not amenable to experimentation. Such computational studies are an integral element of the CTBT R&D seismic monitoring effort, and provide a strong complement to the empirical studies.

In summary, we are successfully addressing issues and questions that arise out of current empirical discrimination. The DIVIDER-CORREO study is an example. In the longer term, we envision using synthetics generated from such simulations for testing and validating discrimination algorithms, investigating decoupling issues, and simulating complicated mining explosions.

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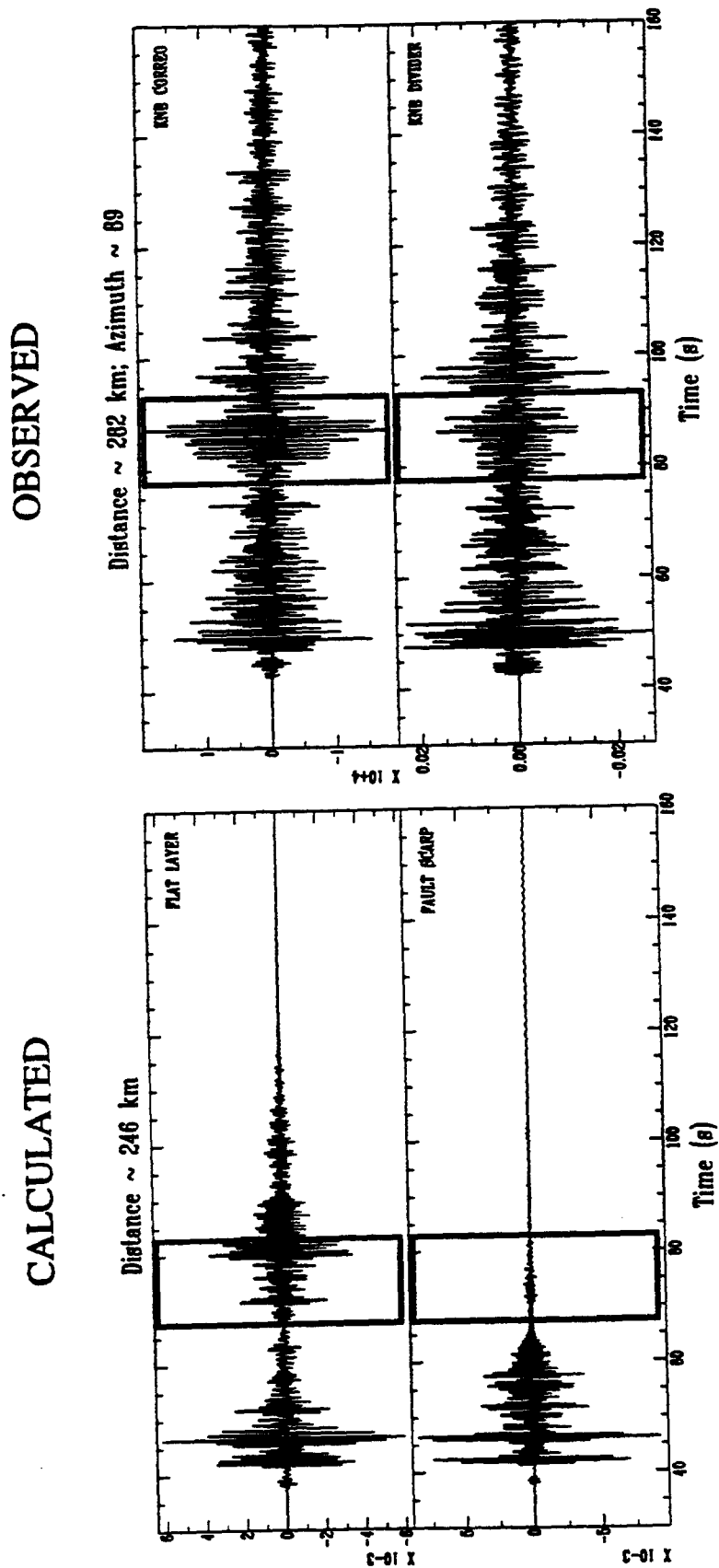
Figure 1. Comparison of the measured and calculated regional waveforms at LLNL Kanab recording station. The highlighted portions are the Lg phase. Early arrivals are the Pg phase. Calculations and observations suggest that the fault significantly affected the Lg wavetrain.
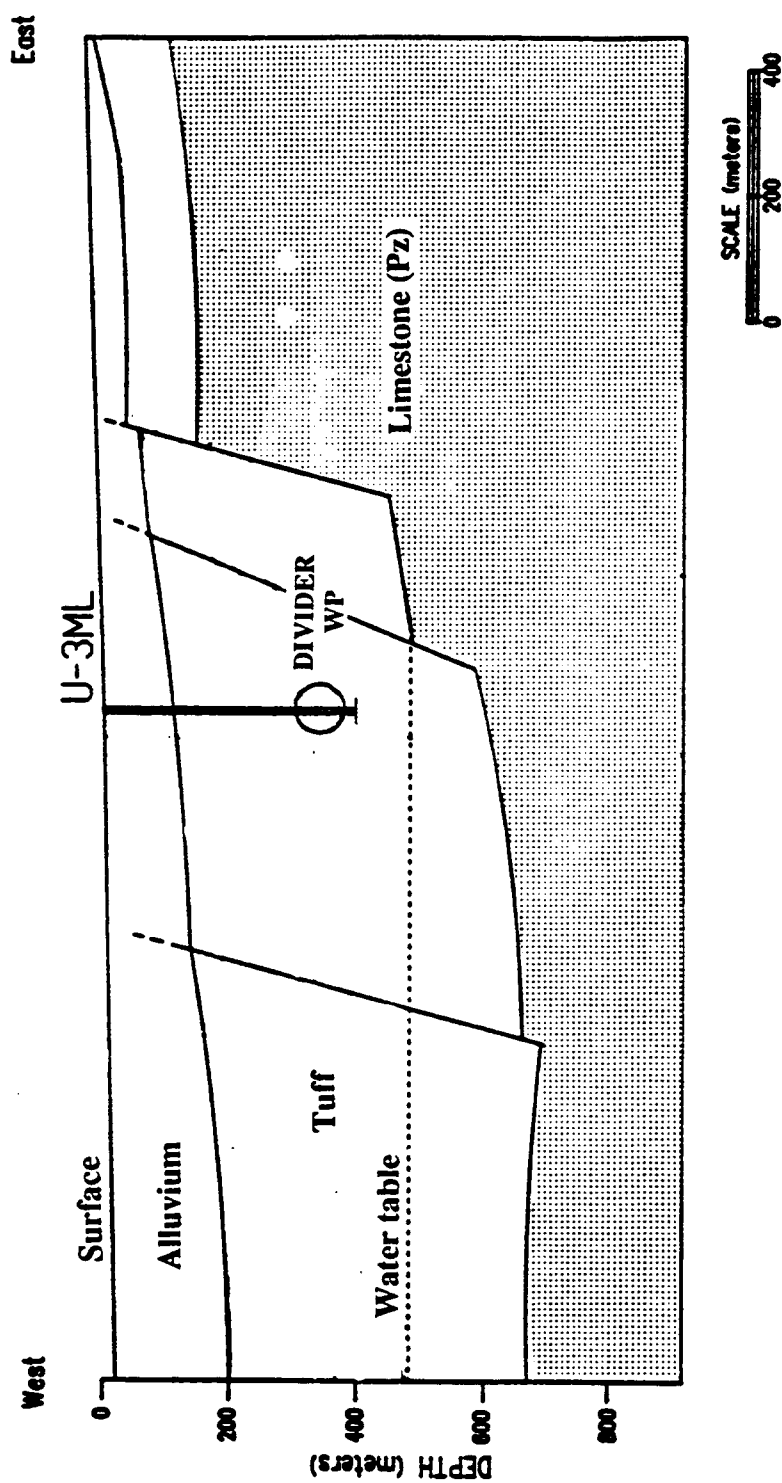
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Figure 2. Geologic cross section across the DIVIDER event site. The stippled region is the Pz limestone. CORREO is similar but without the fault scarp.
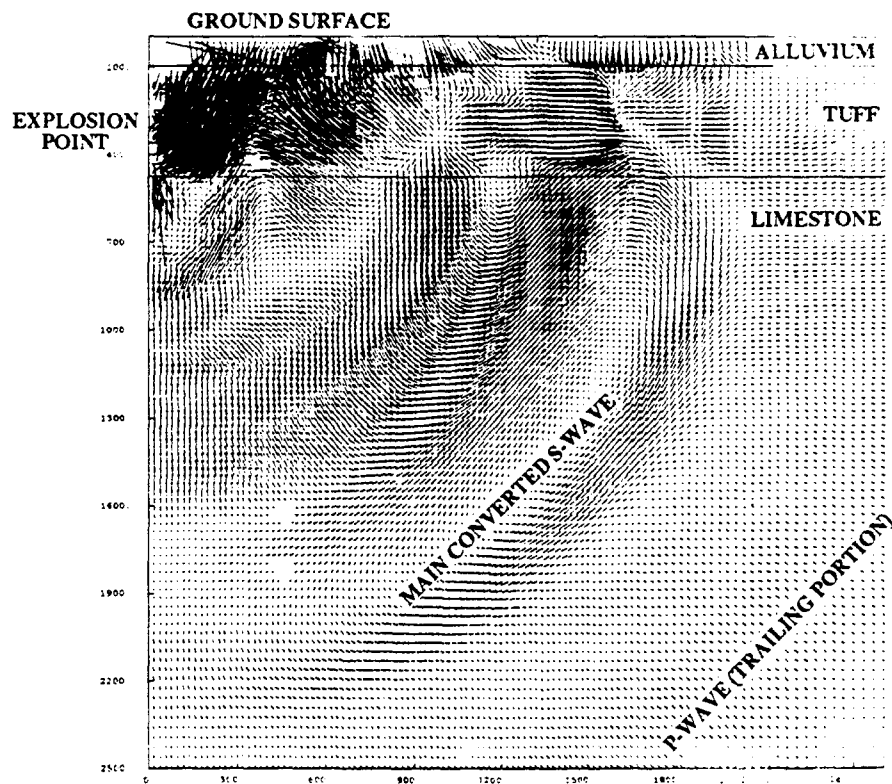
Figure 3a. Particle velocity field for the CORREO calculation at 1 sec.
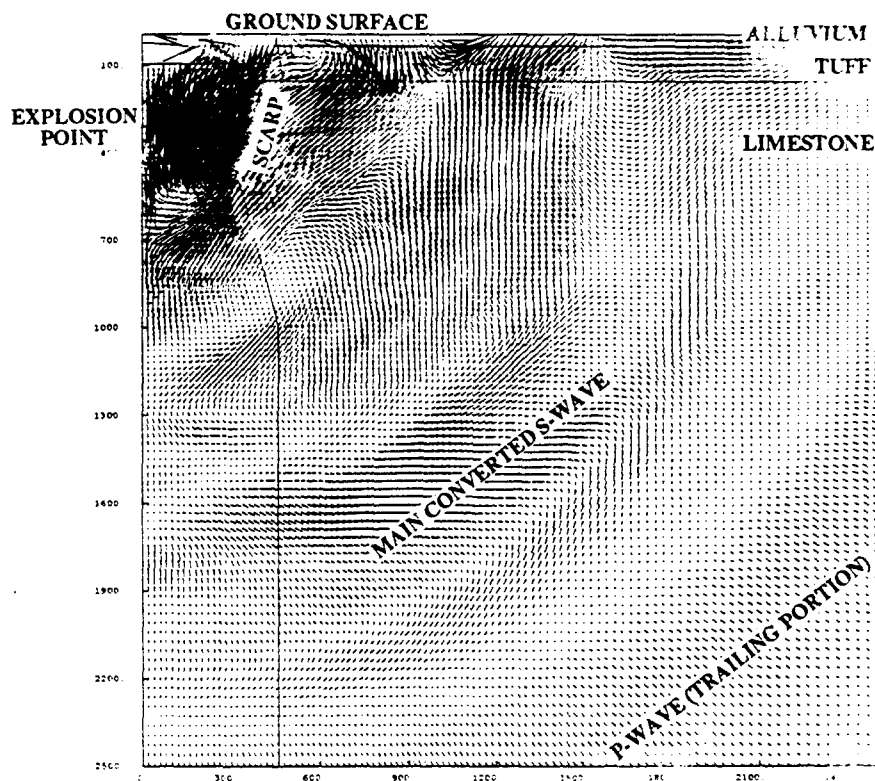

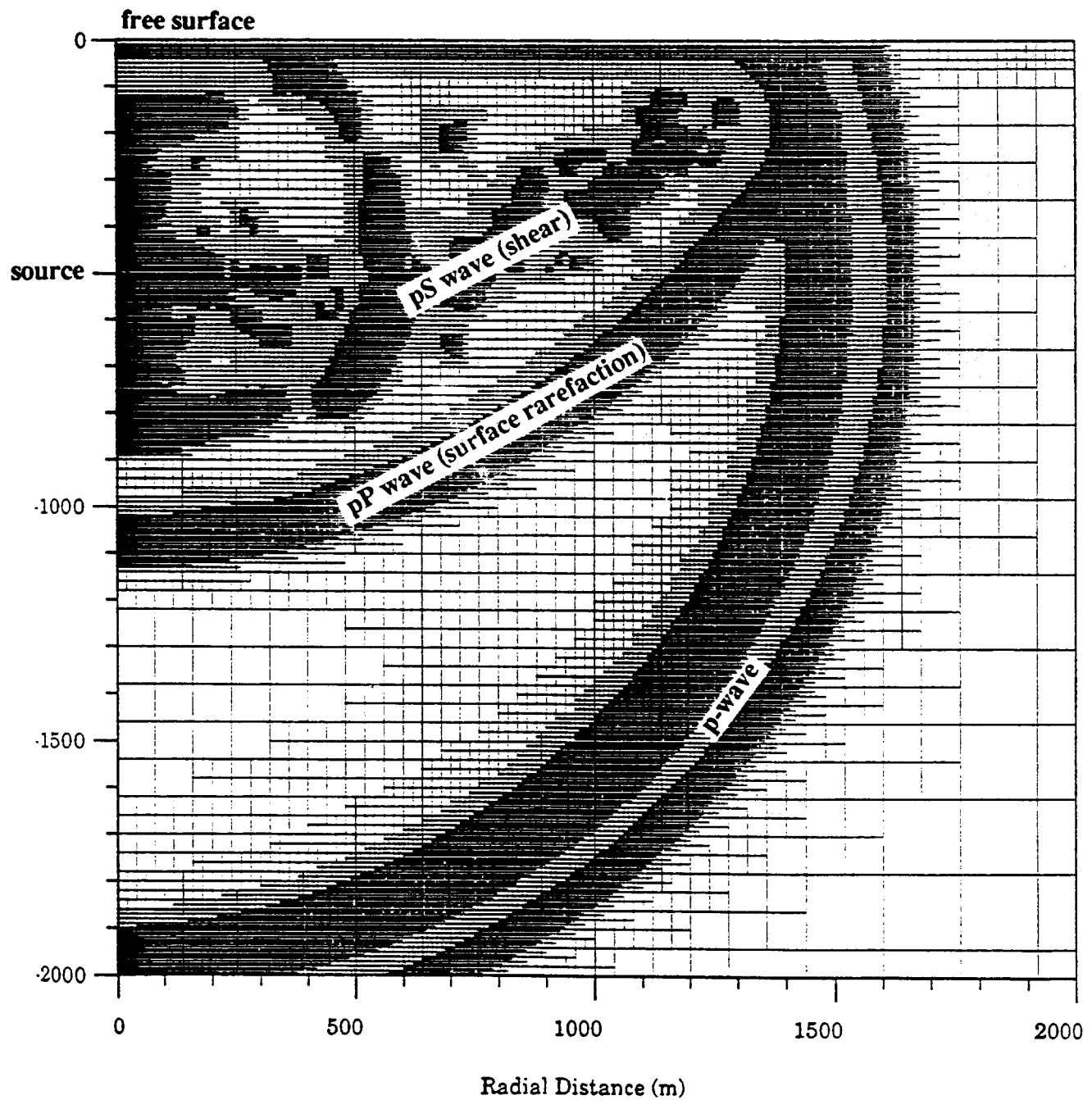Figure 3b. Particle velocity field for the DIVIDER calculation at 1 sec.

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Figure 4. Plot of computational mesh for RAGE calculation at 500 ms. Stress waves produced by instant pressurization of sphere in an elastic half-space. The darkened regions are areas of very high zone resolution.

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